Faculty of Electrical Engineering
Universiti Teknologi Malaysia

VOL. 9, NO. 2, 2007, 60-65

ELEKTRIKA
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Generation of a Homogeneous Glow Discharge in Air at Atmospheric Pressure

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Abstract: A glow discharge has been experimentally investigated in air at atmospheric pressure using two different electrode configurations of a perforated aluminium sheet and stainless steel wire mesh. The observations of the Lissajous figure of voltage-electric charges is used as a method of distinguishing between the glow discharge produced by perforated aluminium sheet and stainless steel wire mesh. The perforated material shows a better glow discharge stabilization than that of stainless steel wire mesh.

Keywords: Electrical discharge, Glow discharge.

1. INTRODUCTION

In general, a glow discharge is found to be stable only in a low pressure discharge of less than a few mbar [1,2]. At atmospheric pressure, the glow discharge is normally unstable, and in most cases [3,4,5] it tends to change to a filamentary discharge, very dependant on the specific gas, the material of the dielectric barrier, the structure of the discharge electrode, the frequency, the gap spacing and the humidity of the gas [1-9].

However, several authors [5,6,10] claim to have obtained a stable glow discharge at atmospheric pressure and have suggested that their success is based on three simple requirements (a) a source frequency above 1 kHz, (b) insertion of a dielectric plate (or plates) between the two metal electrodes and (c) use of helium dilution gas. The ability of helium to produce a stable glow discharge at atmospheric pressure is well known and is said to be related to its low breakdown voltage [11]. To obtain a glow discharge at atmospheric pressure the occurrence of small avalanches under a low field is required [12], and since the breakdown stress of helium at 1 atm is only about 300 V/mm, some 10 times lower than that for air, it is relatively easy to produce a glow discharge. Although helium is good for generating a homogeneous glow discharge at atmospheric pressure, it is however not practical for ozone generation, due to its high cost and the low efficiency of the process.

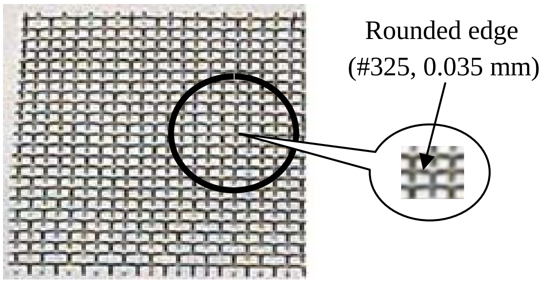
Another interesting result on stabilization of an atmospheric pressure glow discharge (APGD) was reported [1] in its appearance in air, argon and oxygen when using a 50 Hz source and with the use of a fine wire mesh as the discharge electrodes. These experiments have been repeated [4,6] with similar results, and it has also been found that a fine mesh electrodes [2] produces a more stable glow than does a coarse one. Since ozone is commonly generated in air or in oxygen, the possibility of an APGD in air and in oxygen is very important, and this has therefore become the focus of the present investigation.

In the present study, perforated aluminum sheet is introduced as for a comparison with a well established fine stainless steel wire mesh. The basis for this is that the perforated sheet consists of a series-parallel arrangement of small holes with sharp edges, which is expected to produce a higher local electric field strength than does a fine wire mesh (see Figures 1(a) and 1(b)). The higher local electric field in the gap may be sufficient to cause ionization of the gas in the vicinity of the sharp edges. This in turn will produce more micro-discharges near the electrodes, and further will provide a discharge that fills the entire volume of the discharge chamber. If a dielectric barrier is present, the increase in field strength will lead to an increased number of micro-discharges of nanosecond duration [13]. Each micro-discharge consists of a thin almost cylindrical channel, with a tense spot at the metal electrode and spreading into a glow discharge on the dielectric surface.

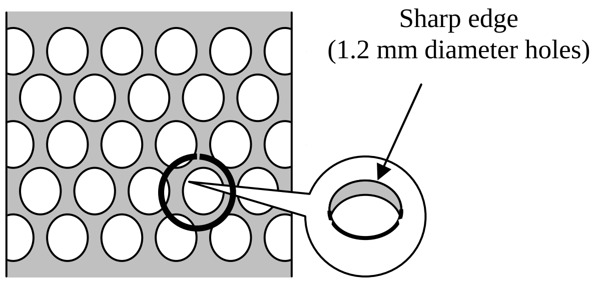
Additionally, a greater perforation density with small diameter holes may produce the same effect as a fine wire mesh, at both low and high voltages [14]. However, with a higher concentration of holes and a sharper edge, the smaller diameters are expected to provide a higher and more uniform electric field for charging the dielectric surface than does the wire mesh. It is also expected that the physical structure of perforated metal such as the shape and diameter of the holes, and the metal thickness will all have an influence on the breakdown mechanism and the discharge stability, and certainly needs further investigation.

2. EXPERIMENTAL SET-UP

Figure 2 shows the experimental arrangement used to compare the two different electrodes structure, using either a plane-to-plane configuration with perforated aluminium sheet with 1.2 mm diameter holes and 23% open area or a fine steel wire mesh sheets of #325 numbers of meshes per inch and 0.035 mm wire diameter. A double barrier arrangement was adopted, with both sides having one electrode sheet (20 mm in length and 20 mm in width) located between the aluminium foil and dielectric barrier.



(a) Fine steel wire mesh



(b) Perforated metal sheet

Figure 1. Physical structure of (a) fine wire mesh; (b) perforated metal electrodes.

The aluminium foil serves as a high voltage electrode on one side of the reactor chamber and as the ground electrode on the other side. Mica sheet 130 μm thick was used as the dielectric barrier, to permit the charge build-up that maintains the plasma from one half-cycle of the supply to the next [12, 13].

The gap spacing and the air flow rate were kept constant at 1 mm and 1 l/min respectively, and a voltage between 1 and 20 kV at a frequency of 50 Hz was used to supply the APGD reactor. Dry air supplied by British Oxygen Company (BOC) with a relative humidity below 20% was used as the input gas. A 240V/20000V, 5 mA, 50 Hz step-up transformer provided the high AC voltage to the electrodes, with the primary voltage controlled by a Variac to give an input to the transformer between 0 and 240 V. The voltage is measured by means of a voltage divider R1 and R2 and the charge signal is obtained with the aid of a 0.22 μF capacitor connected in series to ground (see Figures 2 and 3).

The discharge current is measured using a Pearson Rogowski current monitor (Model 2877) through a 50 Ω resistor connected in series to ground (see Figure 2). The output signals are measured by a digital oscilloscope (LeCroy 9344) with a bandwidth of 500 MHz and a sample rate of 1 GS/s.

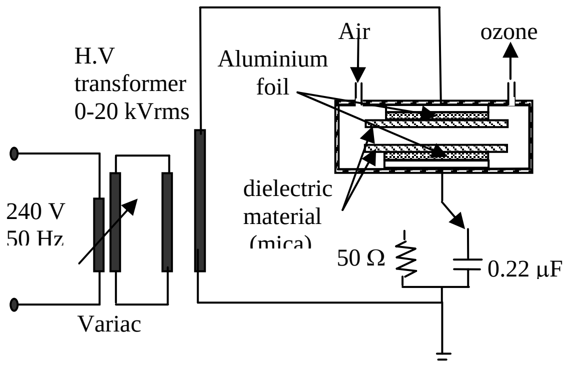


Figure 2. Experimental arrangement for comparison of the glow discharge stability.

3. RESULTS

Visual observations indicated that the discharge was similar when the fine wire mesh was replaced by perforated aluminium. It is therefore difficult to differentiate the stability of the glow discharge between the two configurations. Because of this, the observation of the common discharge behaviour technique using voltage-charge Lissajous figures [4,5,6] was adopted. The discharge behaviour was observed with mesh (#325, 0.035 mm) and perforated aluminium (1.2 mm diameter holes) respectively, at supply voltages of 1.2, 1.4, 1.6 and 1.8 kV for 1 mm gap distance and at supply voltages of 2.8, 3.2, 3.6 and 4.0 kV for 3 mm gap distance.

3.1 Voltage-charge Lissajous Figure

Observation of the Lissajous voltage-charge figure [1] was used to distinguish between glow and filamentary discharges, using the circuit shown in Figure 3. The attenuated high voltage is fed between point X and earth, and the capacitor voltage between point Y and earth.

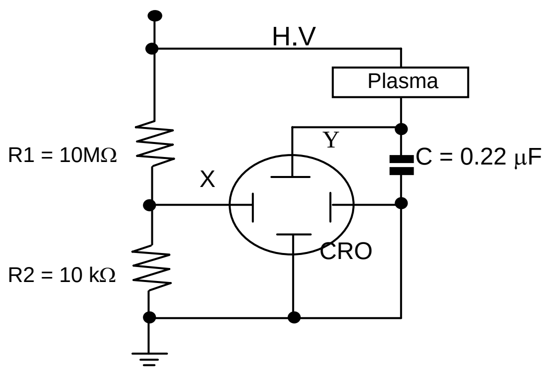


Figure 3. Circuit to measure Lissajou voltage-charge characteristics [4].

The appearance of two voltage lines, as the top and bottom of a parallelogram, was taken as an indication of the existence of a glow discharge. The appearance of a staircase-like waveform, with or without continuous connecting lines, was taken as an indication of the existence of a filamentary discharge and a mixed glow-filamentary discharge respectively, as established by previous researchers [4,10,11]. The resulting Lissajous figures are shown in Figures 4 and 5.

Figure 4 shows the effect of different values of applied voltage when using a wire mesh (#325, 0.035 mm) electrode. It can be seen in Figure 4(a) that, at a voltage as low as 1.2 kV, the Lissajous figure appears as only two straight lines, indicating the existence of the glow discharge. Increasing the voltage to 1.4 kV and then to 1.6 kV produces a mixed glow-filamentary discharge, as is indicated in both Figures 4(b) and 4(c) by the appearance of a staircase-like region in the waveforms. Finally, Figure 4(d) shows that a change from a mixed glow–filamentary to a filamentary discharge appears at voltages of 1.8 kV and above, as is indicated by the existence of continuous connecting lines in the staircase-like regions.

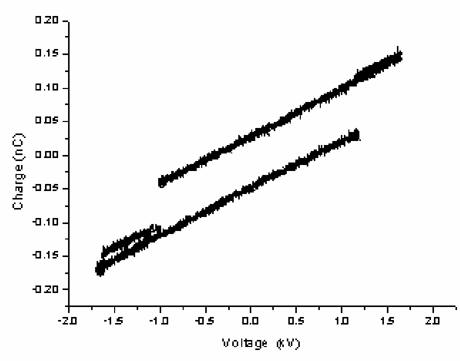
Figure 5 shows Lissajous figures at different value of applied voltage when using perforated aluminium (1.2 mm, 23% open area) electrodes. The two long lines in Figure 5(a) demonstrate that at 1.2 kV a pure glow discharge is produced. At a voltage of 1.4 kV, a slight change toward a mixed glow-filamentary discharge is produced as is evidenced in Figure 5(b).

Increasing the supply voltage to 1.6 kV (Figure 5(c)), results in an increased glow -filamentary discharge, shown by the existence of an extended staircase-like region in the waveform, and this continues up to 1.8 kV as is evidenced from Figure 5(d). Unlike the results of Figure 4, no pure filamentary discharge now occurs at a voltage of 1.8 kV. Increasing the voltage further to 2.0 kV, results in the discharge becoming entirely filamentary. However, for comparative purposes, all the results for the gap spacing of 1 mm in this study are shown up to a maximum of 1.8 kV.

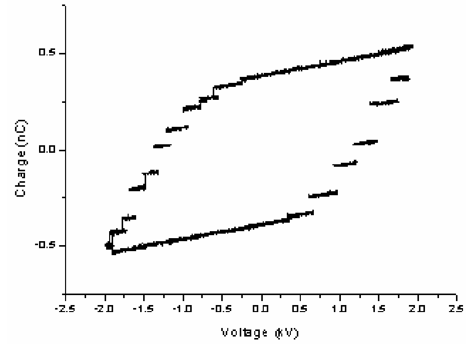
In order to investigate further the effectiveness of perforated aluminium over a fine wire mesh, a comparative study between two arrangements (a fine steel wire mesh and a small diameter of perforated aluminium) involving an increased gap spacing (3 mm) was conducted. The results obtained are shown in Figures 6 and 7 and these confirm the results obtained previously with the gap spacing of 1.5 mm.

Fig 6 shows the effect of different values of applied voltage when using steel wire mesh (#325, 0.035 mm) electrodes at a gap spacing increased to 3 mm. Fig. 9(a) indicates that at 2.8 kV, a slight glow discharge changing toward a mixed glow-filamentary discharge is generated. Increasing the voltage to 3.2 kV generates a mixed glow-filamentary discharge, as is evident from Figs. 9(b). Input voltage of 3.6 kV and 4.0 kV produce similar results, with the glow-filamentary discharge changing to a filamentary discharge, as shown in Figs. 9(c) and (d).

Fig 7 shows Lissajous figures at different value of applied voltage when using perforated aluminium (1.2 mm, 23% open area) electrodes at gap spacing of 3 mm. The two long lines in Fig. 10(a) demonstrate that at 2.8 kV a pure glow discharge is produced. Increasing the voltage to 3.2 kV and then to 3.6 kV generates a mixed glow-filamentary discharge as is evident from Figs. 10(b) and (c). At 4.0 kV, Fig.10(d) shows that the glow-filamentary discharge mixture has changed into a filamentary discharge.



(a)



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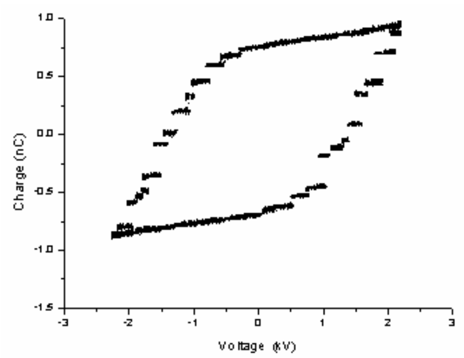

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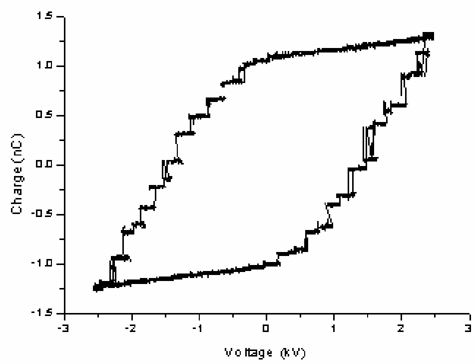
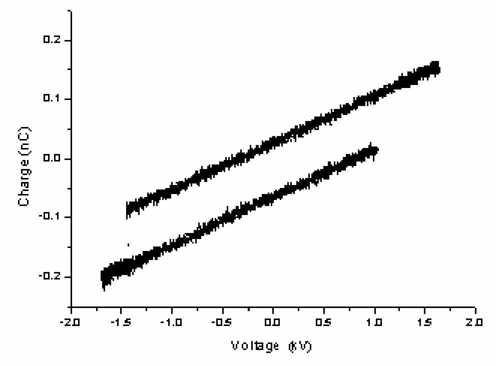


(d)

Figure 4. Voltage-charge Lissajous figure for fine steel wire mesh (#325, 0.035 mm) at (a) 1.2 kV; (b) 1.4 kV; (c) 1.6 kV; (d) 1.8 kV. Gap distance d = 1.5 mm, gas flow rate f_r = 1 l/min, pressure p = 1 bar.



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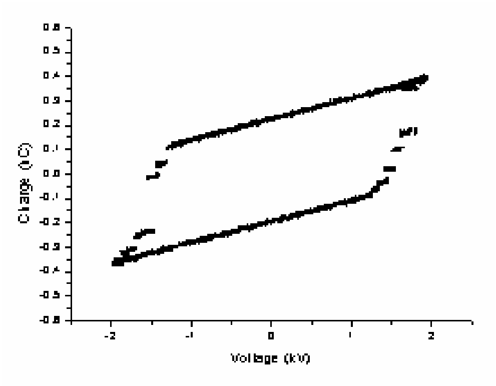

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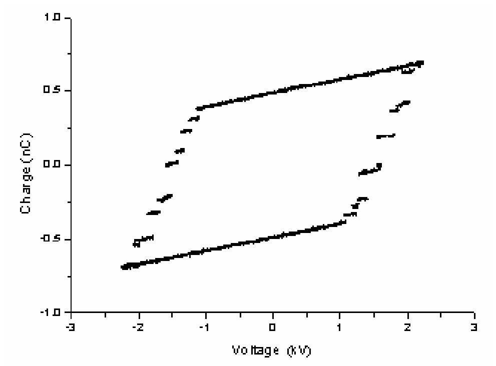

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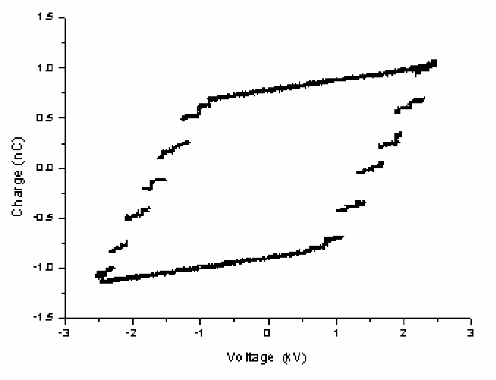
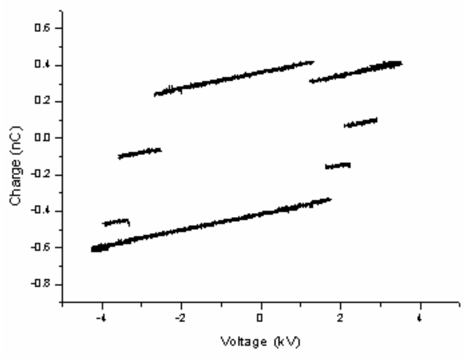


(d)

Figure 5. Voltage-charge Lissajous figure for perforated aluminium (1.2 mm diameter, 23% open area) at (a) 1.2 kV; (b) 1.4 kV; (c) 1.6 kV; (d) 1.8 kV. Gap distance d = 1.5 mm, gas flow rate f_r = 1 l/min, pressure p = 1 bar.



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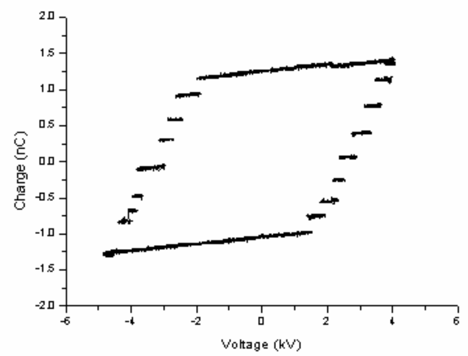

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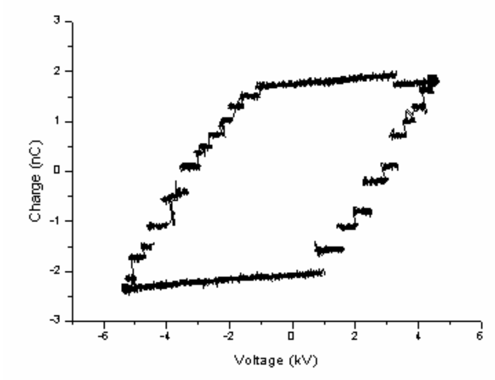

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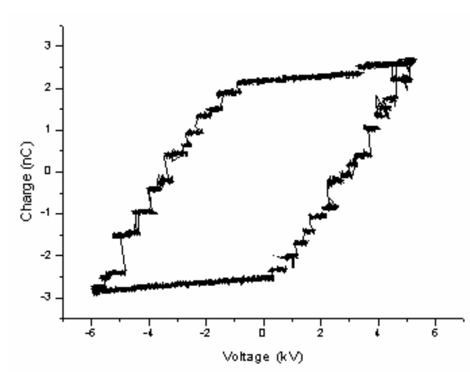
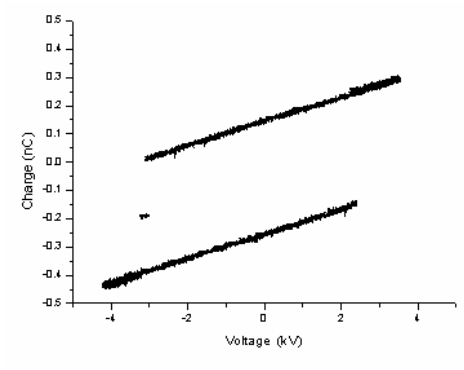


(d)

Figure 6. Voltage-charge Lissajous figure for fine steel wire mesh (#325, 0.035 mm) at (a) 2.8 kV; (b) 3.2 kV; (c) 3.6 kV; (d) 4.0 kV. Gap distance d = 3 mm, gas flow rate f_r = 1 l/min, pressure p = 1 bar.



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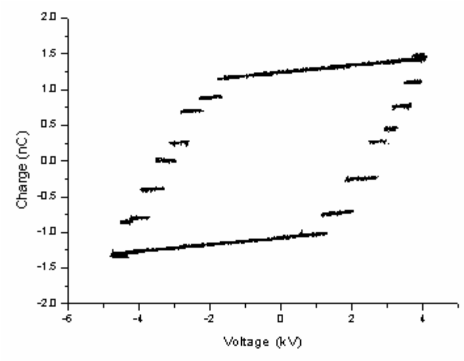

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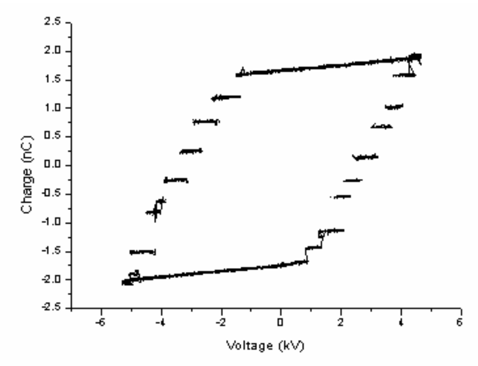
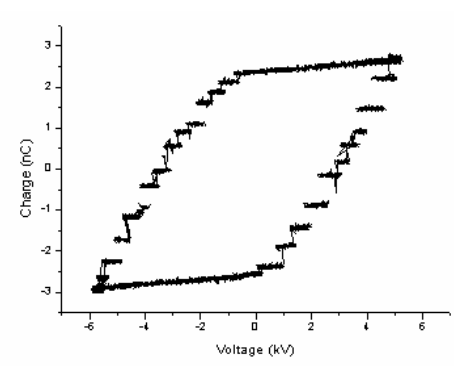


(c)



(d)

Figure 7. Voltage-chage Lissajous figure for perforated aluminium (1.2 mm diameter, 23% open area) at (a) 2.8 kV; (b) 3.2 kV; (c) 3.6 kV; (d) 4.0 kV. Gap distance d = 3 mm, gas flow rate f_r = 1 l/min, pressure p = 1 bar.

4. DISCUSSION

In general, it has been found that perforated aluminium with small holes can generate a homogeneous glow discharge at atmospheric pressure in air at frequencies as low as 50 Hz, gap spacings of 1.5 mm and 3.0 mm and can produces an even more homogeneous glow discharge than does the fine wire mesh electrodes. This is clear by comparing the discharge behaviour of the two configuration using the Lissajous figures of Figures 4 and 5 for gap distance of 1 mm. The same advantages were evident when the gap distance was increased to 3 mm, as shown by the Lissajous figures of Figure 6 and Figure 7. However, the maximum spacing between dielectric plates for a stable glow discharge was only 3.0 mm. Beyond that the glow was unstable and tended to generate a filamentary discharge, which is in general agreement with previous work [1,2,5]. Similarly, the stability of the glow discharge seems to depend on the applied input voltage. With the configuration used in this study, the maximum input voltages at which a stable glow discharge can be maintained were 1.6 kV and 3.6 kV for wire mesh at gap spacing of 1.0 mm and 3.0 mm respectively. Whereas, for perforated aluminium, the stability of the glow discharge can be achieved at a maximum applied input voltage of 1.8 kV and 4.0 kV at the gap spacing of 1.0 mm and 3.0 mm respectively, slightly higher than the wire mesh.

The reason why the glow discharge produced by the configuration with perforated aluminium has a better stability than the wire mesh is unclear, since the simulation results [14] for the electric field strength obtained between the two materials showed that the wire mesh configuration produced a higher electric field strength than did the perforated aluminium. This indicates that the electric field strength does not influence the stability of the glow discharge, and is in general agreement with the finding in previous work [4].

However, it may be the shape and size of the holes, as well as the material used, which helps to distribute uniformly the electric field strength throughout the electrode surface, leading to a more uniform and stable glow discharge on the dielectric surface. The preliminary experimental results indicated that, with small diameter holes of perforated aluminium, the glow discharge produced is more stable than with bigger holes suggesting that the hole shape and diameter both have an influence on the glow discharge stability. It is expected therefore that with smaller diameter perforated holes of different shape (i.e of vee or cone form), a better stability of the glow discharge can be achieved

The effect of the material is also evident, when with the use of perforated aluminium a more stable glow discharge is produced than with perforated zinc or even the steel wire mesh. It can be expected that a better stability of glow discharge can be obtained with the use of perforated copper. This is because the copper has a better oxidation process and produces a higher stress at the electrode surface, which in turn will produce more micro-discharges around the electrode. This assumption provides the opportunity for future research.

5. CONCLUSION

The above finding can be summarised as follows:

a) A homogeneous glow discharge can be produced using a perforated metal electrode configuration instead of the well established fine steel wire mesh .

b) Perforated aluminium with a small hole diameter can be used to generate a stable atmospheric pressure glow discharge in air at a frequency as low as 50 Hz.

c) The atmospheric pressure glow discharge generated by the perforated aluminium attached behind the dielectric barrier produced a better stability than when attached by the wire mesh.

d) The electric field strength does not influence the stability of the glow discharge, and this is in general agreement with the findings of previous work.

e) The stability of the glow discharge depends on the gap spacing and the applied input voltage, which is in general agreement with previous work.

f) The stability of the glow discharge depends on the hole diameter of perforated sheet and the materials used. This was noted in from preliminary experiment and therefore needs further investigation.

g) Perforated copper with small diameter holes is expected to produce a better stability than aluminium, since it gives better oxidation process and produce more micro-discharges around the electrode.

With the above findings, the glow discharge produced by the configuration with perforated aluminium attached behind the dielectric barrier will have a good prospect for industrial application.

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